Effect of long-range transport on local PM10 concentrations in the UK

Citation for published version:
Beverland, IJ, Tunes, T, Sozanska, M, Elton, RA, Agius, RM & Heal, MR 2000, 'Effect of long-range transport on local PM10 concentrations in the UK', *International Journal of Environmental Health Research*, vol. 10, no. 3, pp. 229-238. https://doi.org/10.1080/09603120050127176

Digital Object Identifier (DOI):
10.1080/09603120050127176

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
International Journal of Environmental Health Research

Beverland, I. J., Tunes, T., Sozanska, M., Elton, R. A., Agius, R. M. and Heal, M. R. (2000) Effect of long-range transport on local PM_{10} concentrations in the UK, *Int. J. Environ. Health Res.* **10,** 229-238

http://dx.doi.org/10.1080/09603120050127176

Effect of long-range transport on local PM_{10} concentrations in the UK

IAIN J. BEVERLAND[1], TRYGVE TUNES[2], MALGORZATA SOZANSKA[3], ROBERT A. ELTON[1], RAYMOND M. AGIUS[1] and MATHEW R. HEAL.[4]
[1] Department of Community Health Sciences (Public Health Sciences), University of Edinburgh, Medical School, Teviot Place, Edinburgh EH8 9AG, UK, [2] HMS3, Department of Engineering, Stord/Haugesund College, Skaaregata 125, N-5500 Haugsund, Norway, [3] Department of Geography, University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, UK, [4] Department of Chemistry, University of Edinburgh, West Mains Road, Edinburgh, EH9 3JJ, UK

This study describes the effects of long-range transport of secondary airborne particles on local PM_{10} levels in Edinburgh (UK) during the period 1 January to 31 March 1996. Air mass back trajectories for each day were grouped into six atmospheric transport patterns to examine their influences on local PM_{10} concentrations. Significant differences in receptor PM_{10} concentrations were observed between the trajectory patterns (p = 0.1%). Air masses from Eastern Europe resulted in higher daily PM_{10} averages than any of the other patterns (p = 1.0%). Median PM_{10} concentrations in Edinburgh increased by 10–15 $\mu g\ m^{-3}$ when air mass trajectories were from these regions. This effect should be considered by local authorities to acknowledge that not all PM_{10} sources are possible to control in local air quality management areas. Further evidence of the influence of long-range transport was found by detailed examination of the concurrent development of a pollution episode in Edinburgh, London and Belfast. Differences in the temporal development of the episode in the three cities were attributed to trajectory variations in the proximity of frontal weather systems.
Keywords: back trajectory analyses; pollution episode.

Introduction

Particulate air pollution is associated with a range of effects on human health (COMEAP 1995). Correspondingly, PM_{10} (particulate material with aerodynamic diameter of less than 10 μm) is one of eight important air pollutants controlled by the UK government's National Air Quality Strategy (Department of the Environment 1997, reviewed by DETR 1999). The strategy requires local authorities to evaluate measures they have in controlling sources of PM_{10} .

Airborne particulate matter can be of primary or secondary origin (APEG 1999). Particles emitted directly from a source (the largest contributors being combustion processes) are defined as primary. Secondary particles are formed within the atmosphere from the chemical reactions of atmospheric gases, especially sulphur dioxide, oxides of nitrogen and volatile organic compounds (APEG 1999, QUARG 1996).

The effect of secondary particles on PM_{10} measurements during elevated particulate matter episodes are described by King and Dorling (1997). They suggest that winds entering the UK from the South and East form the majority of breaches of the UK PM_{10} standard (50 $\mu g\ m^{-3}$ expressed as a 24 h running mean; EPAQS 1995). King and Dorling (1997) examined a 29-month period from 1 November 1993 to 31 March 1996 which contained 15 such episodes. Stedman (1998) presents a method to distinguish between primary and secondary particle contributions during periods of elevated PM_{10} in the UK showing that rural sulphate concentrations are indicative of the level of secondary particles.

The study described here investigated effects on local PM_{10} levels in Edinburgh (UK) from trans-boundary transport of secondary airborne particles during the period 1 January to 31 March, 1996. PM_{10} levels in Edinburgh were also compared against London and Belfast in a period of elevated pollution. Statistical analyses showed that trajectories from an Eastern European transport pattern resulted in higher PM_{10} levels in Edinburgh than other transport patterns. Differences in the temporal development of the pollution episode in Edinburgh, London and Belfast were attributed to trajectory variations in the proximity of frontal weather systems.

Methodology

Pollution data

Measurements of PM_{10} have been made on an hourly average basis in central Edinburgh since 15 October 1992. This station is a part of the Automatic Monitoring Network (AUN) in the United Kingdom. PM_{10} is measured by a Tapered Element Oscillating Microbalance (TEOM) instrument (QUARG 1996). The data for London and Belfast were also obtained from TEOM instruments at the London Bloomsbury and Belfast Centre AUN sites, respectively.

Air mass back trajectories

Statistical analyses were conducted on PM_{10} measurements sorted into groups of similar air mass back trajectories. The computation of a back trajectory is based on the general principle of using time-dependent wind fields to calculate where in space a particular air mass has travelled from in order to arrive at the location of the sampling site. Stohl (1998) gives an excellent review of trajectory computation, accuracy and applications. Allowing for the limitations of accuracy discussed by Stohl (1998), a trajectory can be defined as a twodimensional probability field, expressing the likelihood that an air parcel will have passed over a given region of pollutant emission (Samson and Moody 1980). Back trajectories are one of the simplest indications of the potential for emissions from a source to reach a receptor. However, it should be remembered that removal and enhancement processes along the way can be overlooked (Dorling *et al.* 1992). By using classes, instead of singular trajectories, the error from one or two misleading trajectories should be minimised. In this study, the back trajectories were divided into different classes depending on the geographical areas the air masses had passed over prior to reaching Edinburgh.

The trajectories were created by the European Centre for Medium Range Weather Forecasting (ECMWF) Reanalysis Project from the British Atmospheric Data Centre (BADC 1998). Back trajectories (duration = 6 days) were calculated at the 1000 mb pressure level for each day (at 1200 GMT) in the study period. This procedure gave latitude–longitude trajectory co-ordinates that were plotted on a land outline using the ARCINFO Geographical Information System. The trajectories were then divided depending on their geographical similarity. Six distinct classes of trajectories were created: Arctic (AR); Atlantic 1 (A1); Atlantic 2 (A2) (trajectories from the Atlantic Ocean passing over England on route to Edinburgh); Western Europe (WE); Eastern Europe (EE) (trajectories passing over the Baltic Area); and Scandinavia (S) (Fig. 1).

A more detailed examination was made of the differences in the PM_{10} time-series for London, Belfast and Edinburgh during the development of a substantial pollution episode during the period 20 March 1996 to 22 March 1996. To interpret differences in the time series back trajectories were computed and compared for each site at 12 h intervals during the development of the episode.

Statistical analyses

The aim of the statistical analyses was to determine: (1) if there was a difference in contribution to local PM_{10} levels between the six trajectory classes; and if so (2) which classes were different from each other? The Kruskal–Wallis (K–W) non-parametric test for more than two independent samples was used to check for the presence of differences in PM_{10} concentration between the six trajectory classes (Neave and Worthington 1988). The multiple comparison Dunn test (Dunn 1964) was then used to confirm which trajectory classes were different from each other. These two statistical methods have been successfully applied in earlier studies involving cluster-analysis of back trajectories (e.g. Brankov *et al.* 1998) and were found to be appropriate for the present work.

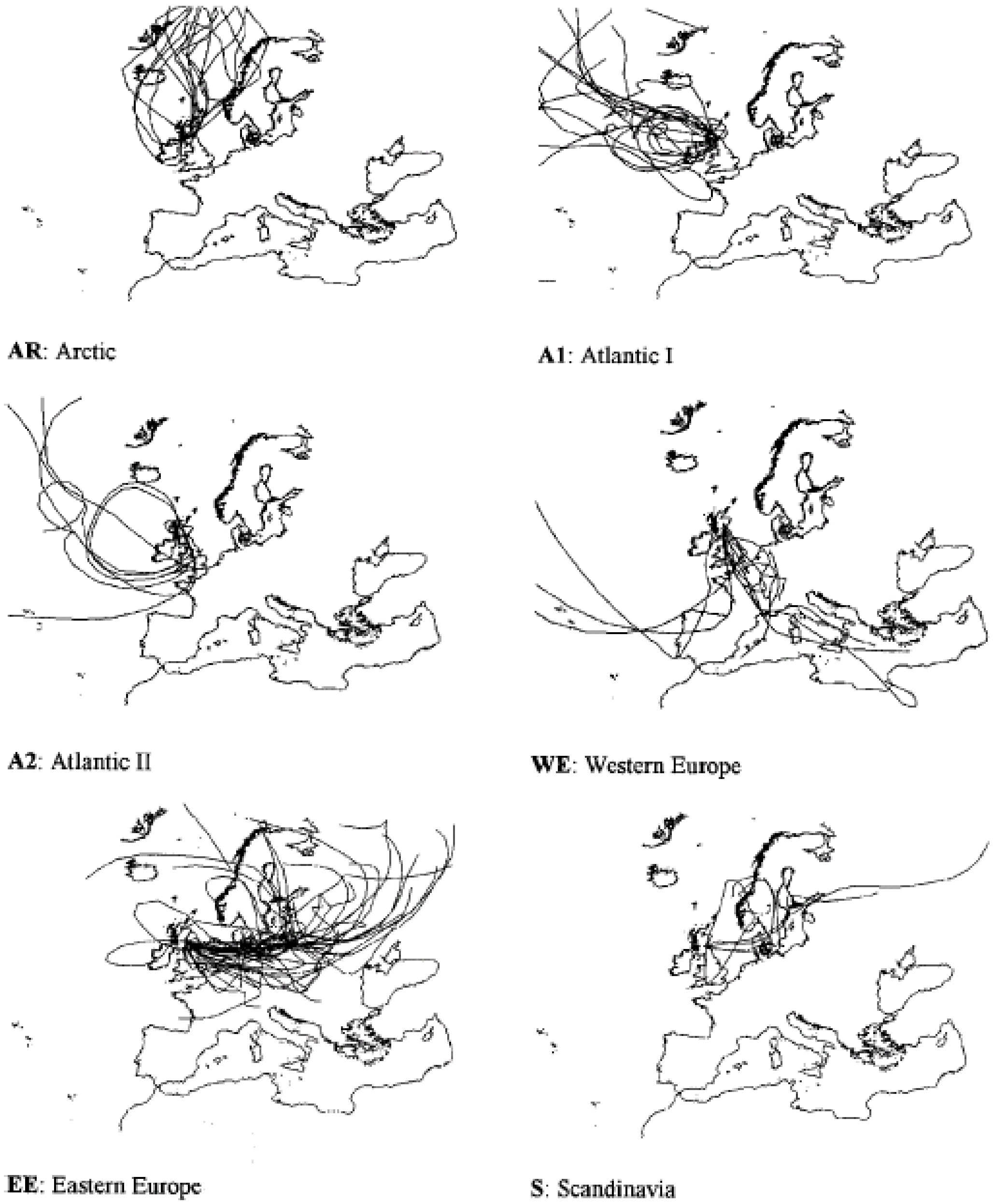


Fig. 1. Classified atmospheric transport patterns for the period 1 January to 31 March 1996. Six-day, 1000mb back trajectories arriving at 1200 GMT in Edinburgh are plotted on each land outline.

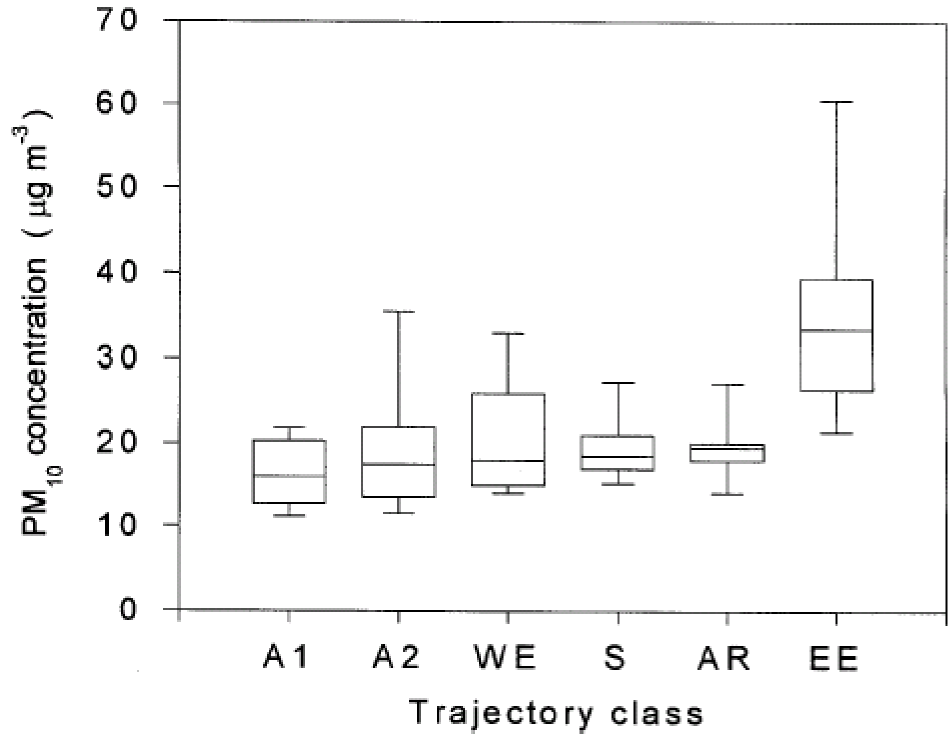


Fig. 2. Box-whisker plot of PM_{10} concentration segregated by trajectory category (see Fig. 1) for 1 January to 31 March 1996. The middle line in the box represents the median in that category. Edges of the box are 25 and 75 percentiles; whiskers are 10 and 90 percentiles. Trajectory categories are: Arctic (AR); Atlantic 1 (A1); Atlantic 2 (A2) (trajectories from the Atlantic Ocean passing over England on route to Edinburgh); Western Europe (WE); Eastern Europe (EE) (trajectories passing over the Baltic Area); and Scandinavia (S).

Table 1. Individual classes and their mean rank from the Kruskal–Wallis test

AR	A1	A2	WE	EE	S
34.7	24.9	29.7	34.5	66.6	34.1

Results and discussion

The median and spread of mean daily PM_{10} concentrations recorded in Edinburgh for each of the back trajectory classes are shown in Fig. 2. These data can be placed in context by comparison with longer-term PM_{10} statistics. Prescott *et al.* (1998) showed that for the same monitoring site during the period October 1992 to June 1995 the mean and standard deviation of daily PM_{10} concentrations were 20.7 and 8.4 m g m^{-3}, respectively. Minimum and maximum daily concentrations during 1992–1995 were 5 and 72 m g m^{-3}, respectively.

The total number of days investigated in the present study was 91. Out of these days, 4 were without daily mean PM_{10} from the AUN site. The K–W hypothesis investigated was H_0 : *The six classes were drawn from populations that have the same median*, against H_1 : *The six classes were drawn from populations that have different medians.* The observations were ranked from 1 to 87 with 1 indicating the lowest PM_{10} level. If H_0 in a K–W test is true the ranks should be randomly distributed between the six classes. The test compares each group's mean rank with the mean of all ranks and makes adjustments for ties (Neave and Worthington 1988).

The mean ranks for the individual classes in the Kruskal–Wallis test are given in Table 1. After correcting for 22 ties, the K–W H_0 hypothesis was rejected at the 0.1% significance level. This meant that it was appropriate to proceed with the Dunn test. For a conventional 1%

significance level the multiple comparison procedure showed that the Eastern European trajectory pattern gave significantly higher PM_{10} levels than all of the other patterns. No other significant differences were noted at the 1% significance level.

In agreement with earlier work in other UK locations (Stedman 1997, King and Dorling 1997) these data suggest that local PM_{10} levels in Edinburgh may have been significantly influenced by imported particulate material in air masses passing over the city. The limited dataset examined in the present study suggests that on average the effect of Eastern European trajectories on the city is an increase in PM_{10} concentration of 10–15 $\mu g\ m^{-3}$. Although the majority of measurements are below the UK environmental quality standard for PM_{10} (50 $\mu g\ m^{-3}$ measured as a 24 h running mean; EPAQS 1995), earlier epidemiological research has shown that concentration increases of this magnitude are significantly linked to health outcomes in the population of Edinburgh. In the period 1992–1995 (PM_{10} concentration ranges given above) an increase of 4.8% (95% CI: 0.9% to 8.9%) in cardiovascular emergency emissions in the over 65 age group was associated with an increment of 10 $\mu g\ m^{-3}$ in the three-day antecedent moving mean of PM_{10} (Prescott *et al.* 1998).

To examine the temporal development of pollution episodes across the UK, a period of the three-month dataset was selected when there was marked and rapid development of episode conditions in Edinburgh. One such period was on 20–21 March 1996 when PM_{10} concentrations rose from approximately 20 $\mu g\ m^{-3}$ (which, as noted above, is a fairly typical concentration in central Edinburgh) to over 120 $\mu g\ m^{-3}$ in less than 24 h (Fig. 3). It was suspected that increases in London and Belfast may have occurred slightly earlier and later, respectively, as a result of differences in distance from Eastern European sources. However, examination of the time series in Fig. 3 indicated that the data were more complex than this.

The London data show a sharp rise of a similar temporal gradient as observed in Edinburgh. This increase took place 12–24 h before the rise in concentrations in Edinburgh. However, the London time series shows a very pronounced drop at approximately 0600 GMT on 21 March 1996. This pattern was consistent with a number of other automatic urban network sites in London.

In contrast, the time series for Belfast shows slightly higher PM_{10} levels (up to 80 $\mu g\ m^{-3}$) on 20 March. Fourteen hours later the levels in Belfast had dropped to be more consistent with the measurements in Edinburgh. A strong similarity exists between the time series for Edinburgh and Belfast on 21 March during the development of the episode.

These differences can be interpreted by examining the air mass back trajectories arriving at each of the three sites (Fig. 4). On 20 March when relatively low concentrations ($< 20\ \mu g\ m^{-3}$) were observed in Edinburgh the trajectories for this site originated to the East but did not cross the heavily industrialised regions to the south of the Baltic Sea [Fig. 4(a)]. In contrast, concentrations of approximately 60 $\mu g\ m^{-3}$ were observed in London which had a back trajectory in close proximity to this southern Baltic area. Belfast also exhibited relatively high concentrations (approximately 40 $\mu g\ m^{-3}$) associated with an Atlantic trajectory passing over parts of southern England and Wales. Twelve hours later the trajectory for Edinburgh had not changed greatly [Fig. 4(b)]. In contrast, the trajectory for Belfast was now also from the same area over northern Denmark. Both sites exhibited relatively low PM_{10} concentrations ($< 20\ \mu g\ m^{-3}$). The trajectory for London had also changed considerably by this point and showed evidence of relatively slow movement over eastern France and the Paris area. Very high PM_{10} concentrations (approximately 100 $\mu g\ m^{-3}$) were observed at this time.

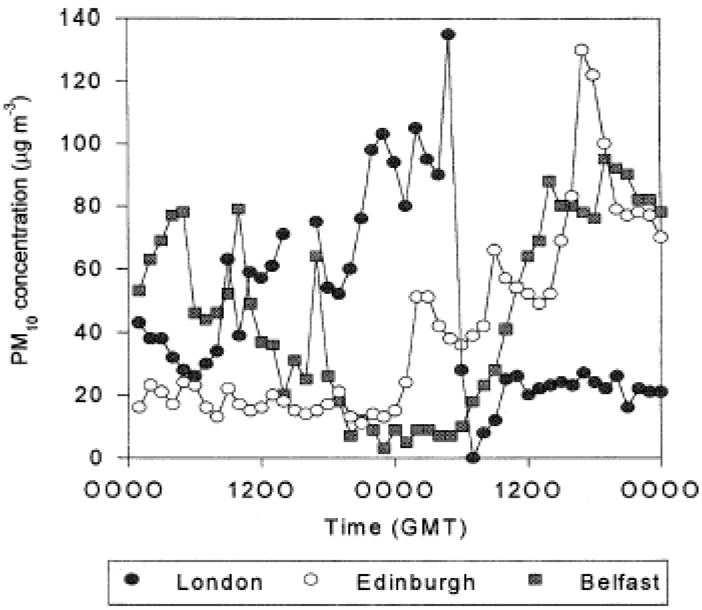
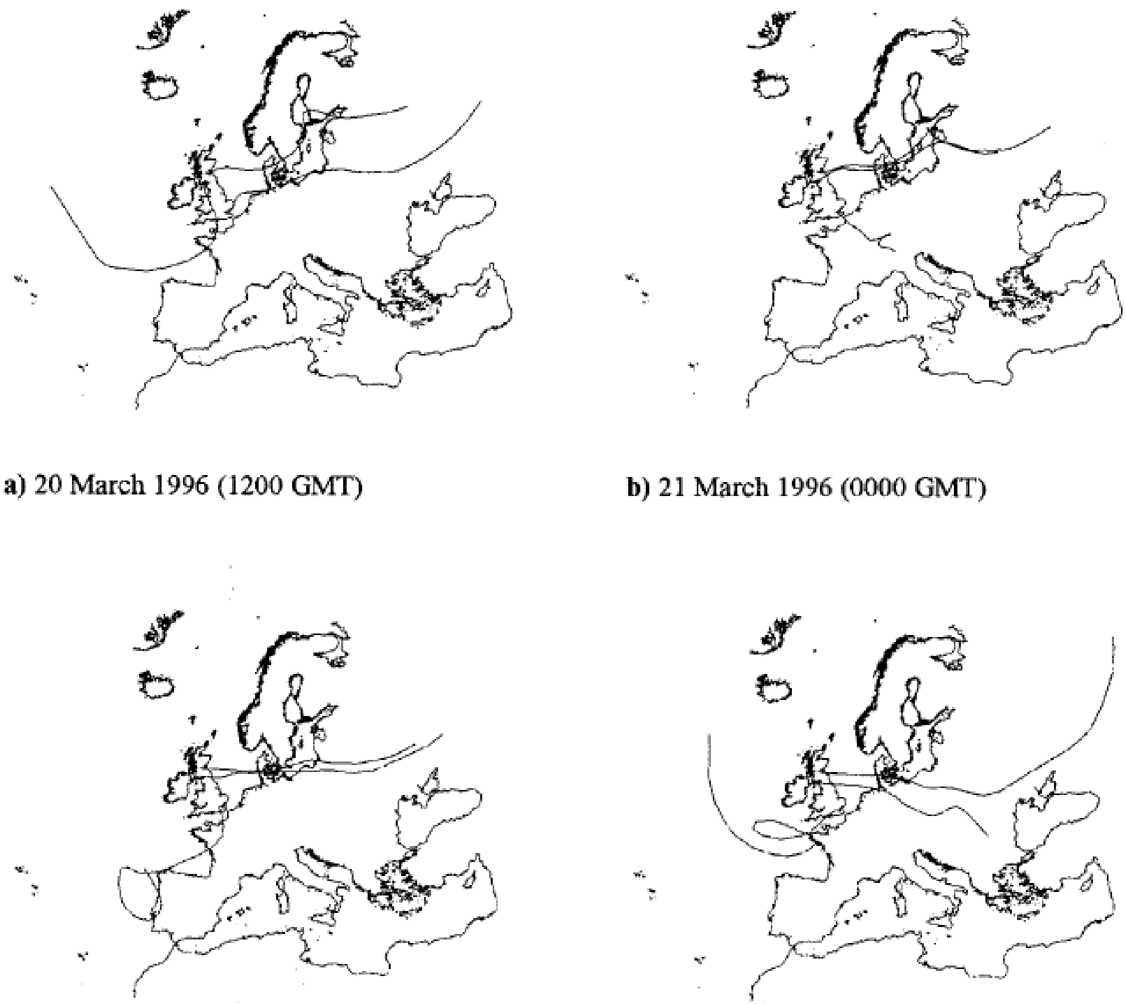


Fig. 3. Development of pollution episode across the UK on 20–21 March 1996.



a) 20 March 1996 (1200 GMT)

b) 21 March 1996 (0000 GMT)

c) 21 March 1996 (1200 GMT)

d) 22 March 1996 (0000 GMT)

Fig. 4. Back trajectories for Belfast, Edinburgh and London, arranged according to launch day and time.

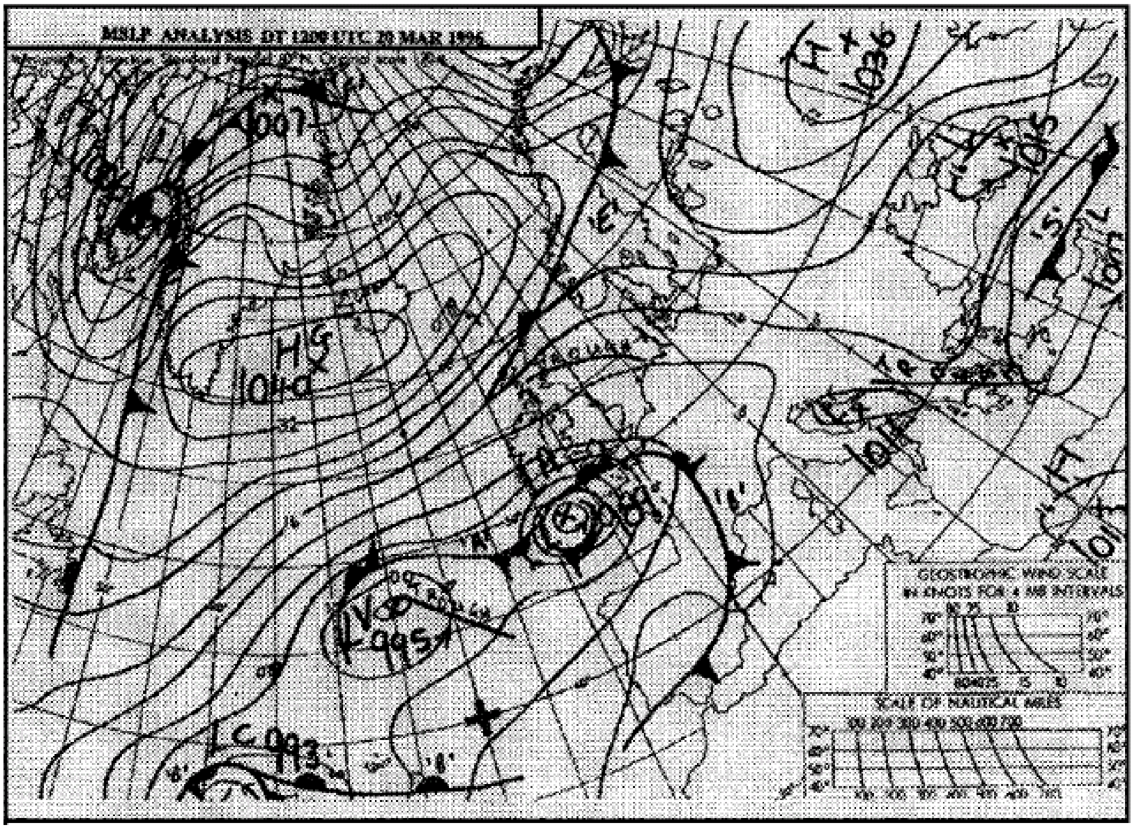


Fig. 5. The pressure systems influencing air mass flow over the UK at 1200 GMT on 20 March 1996.

At 1200 GMT on 21 March the eastern trajectories for Edinburgh and Belfast had moved south to cross parts of Poland [Fig. 4(c)]. At this time concentrations began to rise very rapidly towards levels experienced in London 12–18 h earlier. The London trajectory had changed again to air mass source regions in the west of France and Spain. This coincided with a collapse in PM_{10} levels to relatively constant concentrations of approximately 20 m g m^{-3}. This situation remained relatively unchanged 12 h later with Eastern European trajectories and high PM_{10} concentrations for Edinburgh and Belfast, and a westerly trajectory and low PM_{10} concentration in London [Fig. 4(d) and Fig. 3].

The contrasting trajectories and pollution levels in the three cities can be interpreted from the prevailing synoptic situation. Figure 5 shows the presence of a centre of low pressure and occluded front in the English Channel at 1200 GMT on 20 March. The rapid fall in pollution concentrations in London at approximately 0600 GMT on 21 March coincided with the surface front reaching the capital with a corresponding change in air mass (to much less polluted air behind the front). The front did not reach Edinburgh and Belfast. However, the effect of the movement of the centre of low pressure was to shift the air mass trajectories into source regions in the vicinity of the Baltic States resulting in the sustained development of the pollution episode in the north of the UK.

Conclusions

PM_{10} levels were examined during a period of three months when episodes of particulate pollution were taking place. The occurrence of episodes was influenced by long-range transport from Eastern European source regions. PM_{10} concentrations in Edinburgh increased by 10–15 m g m^{-3} when the air mass trajectories were from these regions. These data confirm that local PM_{10} is often affected by sources out with local authority control and that PM_{10} pollution

requires additional regional-scale regulation as with sulphur and ozone precursors.
Spatial variations in the development of one pollution episode were examined at three different locations in the UK. The temporal development of the episode was markedly affected by long-range transport patterns which in turn were influenced by the relative position of the monitoring sites in relation to the prevailing synoptic weather pattern. Therefore it is difficult to generalise the relationship between daily ‘weather type’ and PM_{10} pollution on a national basis even for a country as small as the UK. It is interesting to note that quite a pronounced relationship can be noted between long-range transport and local air quality using relatively simple isobaric back trajectories. It should be useful to extend this type of analysis to longer time periods using more accurate three-dimensional back trajectories.

Acknowledgement
TT thanks the European Union Leonardo da Vinci Programme and the State Education Loan Fund of Norway for funding project work in Edinburgh.

References

APEG (1999) *Source apportionment of airborne particulate matter in the United Kingdom. Report of the Airborne Particles Expert Group (APEG)*. Prepared on behalf of the Department of Environment, Transport and the Regions (DETR). London: The Stationery Office.
BADC (1998) World wide web server of the British Atmospheric Data Centre (BADC) at the Rutherford Appleton Laboratory. http://www.badc.rl.ac.uk/ (July).
Brankov, E., Trivikrama Rao, S. and Potter, P.S. (1998) A trajectory-clustering-correlation methodology for examining the long-range transport of air pollutants. *Atmospheric Environment* **32**, 1525–1534.
COMEAP (1995) *Committee on the Medical Effects of Air Pollutants (COMEAP): Non-biological particles and health*. London: HMSO.
DETR (1999) *Review of the United Kingdom National Air Quality Strategy*. Department of Environment, Transport and the Regions (DETR) Consultation Document. London: The Stationery Office.
DoE (1997) *The United Kingdom National Air Quality Strategy*, CM 3587. Department of the Environment (DoE). London: The Stationery Office.
Dorling, S.R., Davies, T.D. and Pierce, C.E. (1992) Cluster analysis: a technique for estimating the synoptic meteorological controls on air and precipitation chemistry–method and applications. *Atmospheric Environment* **26A**, 2575–2581.
Dunn, O.J. (1964) Multiple comparisons using rank sums. *Technometrics* **7**, 241–252.
EPAQS (1995) *Particles. The Expert Panel on Air Quality Standards*. London: HMSO.
King, A.M. and Dorling, S.R. (1997) PM_{10} particulate matter–the significance of ambient levels. *Atmospheric Environment* **31**, 2379–2381
Neave, H.R. and Worthington, P.L. (1988) *Distribution-free tests*. London: *Unwin Hyman*.
Prescott, G., Cohen, G., Elton, R., Fowkes, G. and Agius, R. (1998) Urban air pollution and cardiopulmonary ill-health–a 14.5 year time series study. *Occup. Environ. Med.* **55**, 697–704.
QUARG (1996) *Airborne particulate matter in the United Kingdom. Third Report of the Quality of Urban Air Review Group*. UK Department of the Environment. London: HMSO.
Samson and Moody (1980) Trajectories as two-dimensional probability fields. In *Air Pollution Modelling and its Applications* (C.D. Wispelaere, ed.), Vol. I, pp. 43–53, New York.
Stedman, J.R. (1997) A U.K.-wide episode of elevated particle (PM_{10}) concentration in March 1996. *Atmospheric Environment* **31**, 2381–2383
Stedman, J.R. (1998) The secondary particle contribution to elevated PM_{10} concentrations in the UK. *Clean Air* **28**, 87–93.
Stohl, A. (1998) Computation, accuracy and applications of trajectories–a review and bibliography. *Atmospheric Environment* **32**, 947–966